RESEARCH DEPARTMENT

SOUND INSULATION AND ACOUSTICS OF THE NEW STUDIOS IN THE CENTRE BLOCK, BUSH HOUSE

Report No. B-072

(1960/17)

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ERRATUM

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Page 5, Fig. 4, Definition of γ, *last word, for* "studios" *read* "structure"

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(W. Proctor Wilson)

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SUMMARY

This report describes the design, with respect to acoustics and sound insulation, of the studios recently built in the Centre Block of Bush House. The principles of design are not new but in this application there was considerable compromise on grounds of cost and appearance. The first section, dealing with sound insulation, describes how the design was started from a new examination of the insulation requirements between various types of room and from measurements carried out in the steel-framed building in its original state. The second section shows how aesthetic requirements, among them being the provision of flat wall surfaces and the avoidance of "little holes", made it necessary to use hitherto untried sound absorbing constructions.

The studios have proved adequate with respect to sound insulation, and acoustically satisfactory except for some flutters which were cured by orthodox means after the studios had gone into service.

1. INTRODUCTION

1.1. General Remarks

The transfer of the Overseas Services from 200 Oxford Street necessitated the construction of studios and associated technical areas on the 2nd, 3rd, 5th, 6th and 7th floors of the Centre Block of Bush House. The design of the studios was started early in 1955 by the Bush House architect, in collaboration with the B.B.C. Building Department. As Building Department was temporarily without an acoustics specialist, the design of the structure of the studios, where questions of sound insulation and reduction of structure-borne sound were concerned, was guided by Research Department. This department was also responsible for the acoustic treatment in the 2nd floor suite in the Centre Block and for sound insulation and acoustics of the temporary areas in the N.W. wing. With the appointment of a new acoustics specialist in the middle of 1955, Building Department assumed responsibility for the acoustic treatment of the remainder of the Centre Block areas.

This report describes first the measures adopted to ensure adequate sound insulation in the building. The existing steel frame presented problems in sound insulation, and the transmission of sound through this structure was studied experimentally before the design was started. A supplementary investigation was also made in the Belfast studio centre to study the behaviour of steel frames in brick shells.

A brief account is given of the acoustic treatment of the studios with special reference to new features, together with representative measurement data on sound insulation and acoustics.

1.2. Layout of Studios in the Block

The studios in the Centre Block are situated on the 2nd, 3rd, 5th, 6th and 7th floors. On each floor the studio suites form a single row between two corridors, on the other sides of which are offices providing insulation from traffic noise outside the building. Fig. 1 shows the relative positions of the studios in the block.

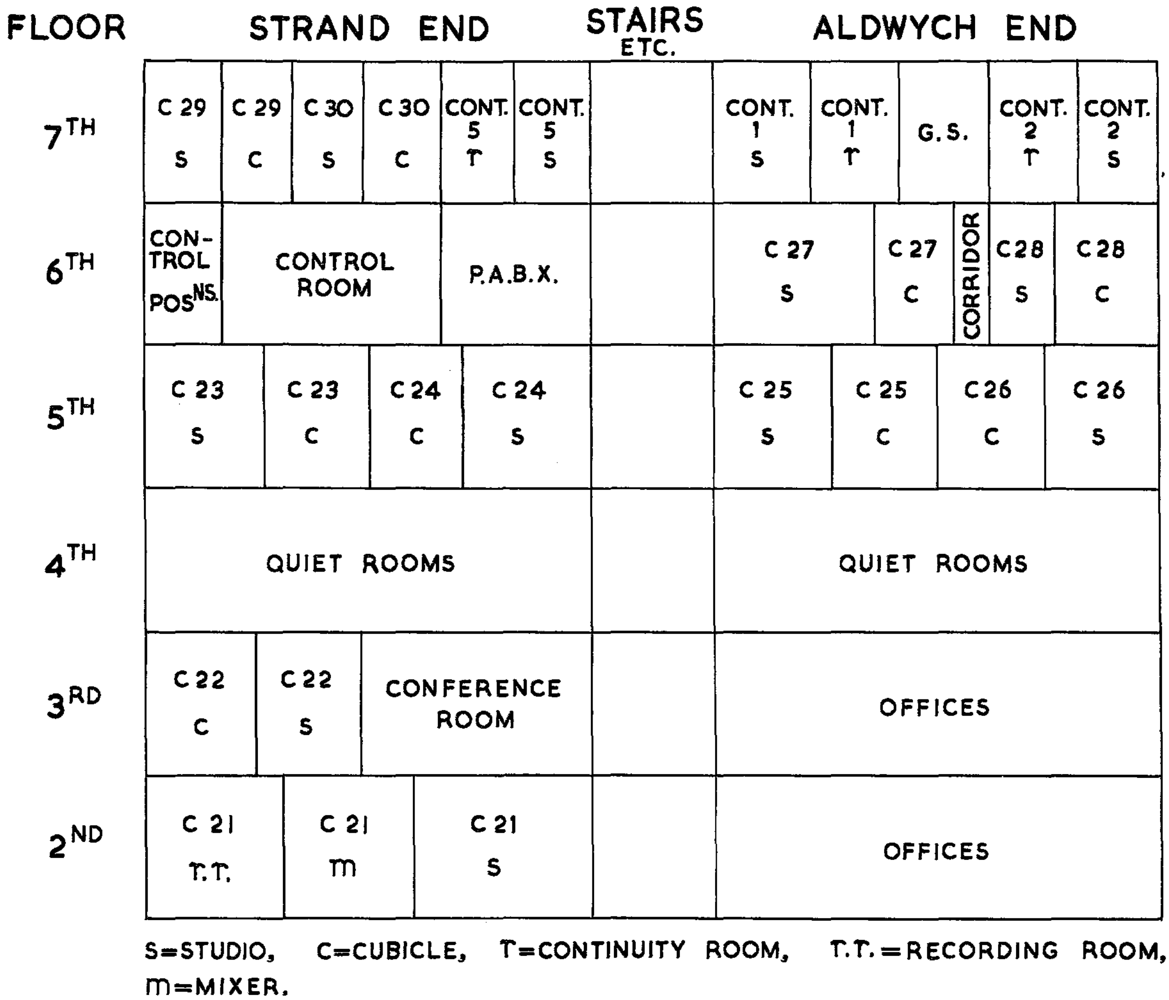

Fig. 1 - Layout of studios, cubicles, etc., in the Centre Block, Bush House

On the 6th floor, Strand end, the central part is occupied by the control room and there are continuity and listening rooms along the outside walls. The 4th floor is occupied by relatively quiet areas, such as a conference room and the PABX apparatus room, and thus causes no risk of noise in the studios above or below. Similarly, the 1st and 8th floors are office accommodation and may therefore be disregarded apart from being a source of footsteps noise. The main ventilating plant is on the 8th floor and discharges air to the other floors through vertical shafts

near to the lift shafts. An exception is the fan for the 2nd floor suite which is in a room separated by a corridor from the suite. No special problems in sound insulation arise from the layout; the main source of interfering sound in any studio is programme from loudspeakers in nearby control cubicles.

2. SOUND INSULATION

2.1. Requirements in Sound Insulation

Design figures were required for sound insulation between the following types of area:

A talks studio and its own cubicle.
A talks studio and a cubicle monitoring a different programme.
Two studios.
Two cubicles.
Studio or cubicle and corridor.

It will be realised that the studios, which are used principally for talks, require a very low level of background noise. A cubicle or control room can have a slightly higher level of interfering programme noise but must be free from appreciable random noise, such as that due to ventilation. The reasons for these statements are given in a recent Research Department report.[1]

In fact, the most stringent requirements for sound insulation are those for a talks studio adjacent to a cubicle containing a loudspeaker radiating a different programme. The sound insulation between two talks studios or two cubicles with different programmes need not be so high. Between a studio and its own cubicle slightly less insulation can be tolerated, though it must not fall at low frequencies to a point at which "howl-round" starts between the cubicle speaker and the studio microphone. The sound insulation between a studio and areas carrying foot or vehicle traffic cannot be specified generally, but must be determined by consideration of the noise level of the traffic.

Fig. 2 shows the desired insulation for the cases discussed, plotted as functions of frequency. The curve for studio-to-cubicle insulation is based on experience gained since the introduction of the LSU/10 loudspeaker; that for cubicle-to-cubicle is the result of special tests carried out in connection with the design of Bush House Centre Block, while that for a studio from a cubicle not monitoring the same programme was recently determined in connection with tape editing suites (in which studios are often necessarily placed near to rooms used for general tape editing work). The required insulation rises with increasing frequency owing to the rising sensitivity of the ear, but this rise is not maintained above 1 kc/s since the energy in the speech spectrum starts to fall before that frequency is reached.

Provision must be made also against the transmission of sound directly through the structure of the building. In accordance with previous experience in Belfast,[2] Swansea and other centres, the desired protection was specified as a figure representing the permitted noise level in the studio caused by the Research Department tapping machine* at the location of the noise source. The noise was measured in

*This is a device for producing impacts similar to those produced by footsteps; it is constructed according to a specification in British Standard 2750, except that the number of blows per second is five instead of ten as specified in the standard.

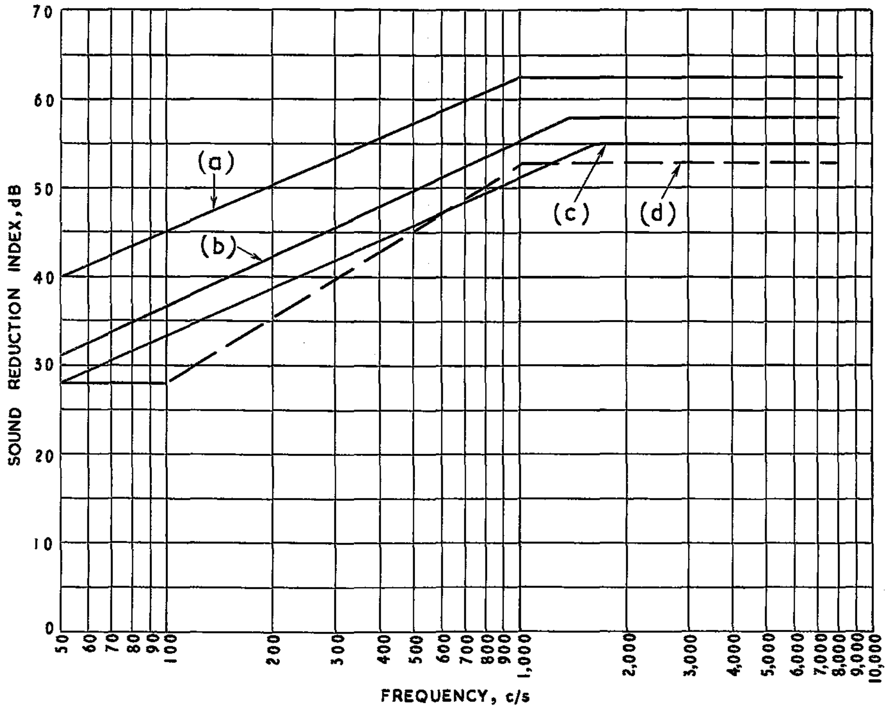

Fig. 2 - Sound insulation required between areas in talks studio suites
(a) studio from cubicle with another programme
(b) studio from studio
(c) cubicle from cubicle
(d) studio from own cubicle

octave bands and summed by the method of Mintz and Tyzzer[3*] to give a total noise figure. The permitted value is 56 dB.

2.2. Preliminary Study of the Building

Before the design of the studio shells could be started it was necessary to examine the sound propagation in the building structure itself. This is of steel with concrete cladding, and listening tests showed that impulsive sounds originating anywhere in the building were transmitted readily to all other parts. On the other hand, airborne sound-insulation between floors was already reasonably good owing to the high mass per unit area of the construction. Fig. 3 shows the construction of the floors and ceilings and indicates the method of attachment to the main reinforced concrete structure. The total depth between the floor and the ceiling of the storey below is 23 in. (58 cm), and the mass approximately 390 kg/m².

Fig. 4, curve (a), shows the mean measured sound reduction index (S.R.I.) between successive storeys of the building. This represents the inverse of the sum

*Since this work was carried out, this method of summation has been replaced by that of Stevens,[4] which is based on the most recent determinations of the equal-loudness contours for continuous spectrum noise.

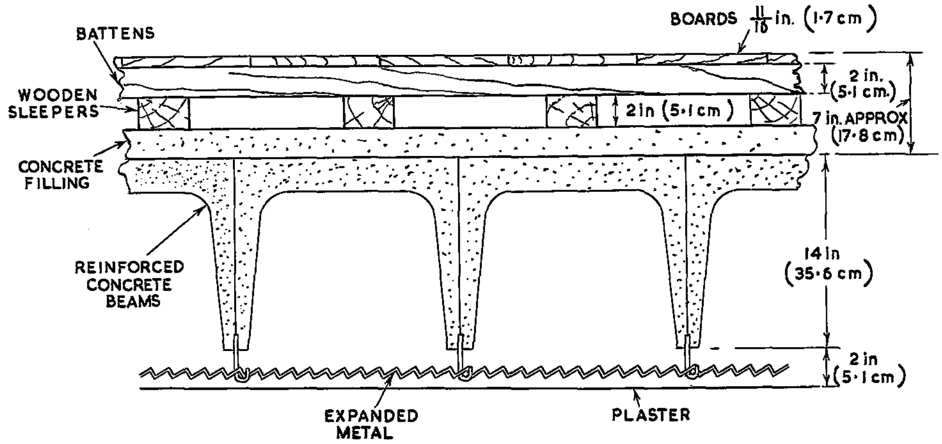

Fig. 3 - Diagram showing construction of floors in the Centre Block, Bush House

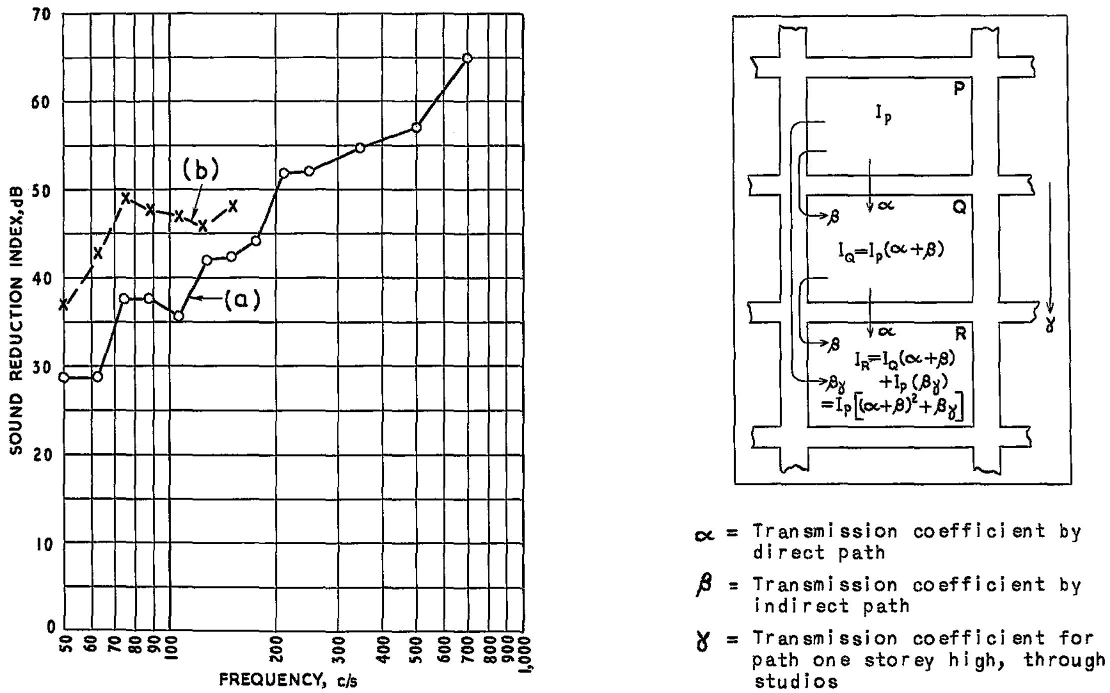

Fig. 4 - Measured sound reduction index between floors, before studio construction
(a) between successive floors P to Q or Q to R (mean of two)
(b) between alternate floors P to R (mean of two)

of the direct transmission through the intervening floor and the flanking transmission down the walls and steel stanchions. The relative magnitude of these two contributions was determined, as described below, by making measurements also between alternate storeys. Fig. 4, curve (b), shows the mean curve of S.R.I. between pairs of storeys separated by a single intervening storey. The principle of the method depends upon

the fact that the direct and flanking transmissions are generally attenuated by different amounts with distance from the source.

The inset in Fig. 4 represents three rooms P, Q and R in successive storeys. Let α be the intensity in Q for unit intensity in P, due to sound passing directly through the floor of P; α is known as the transmission coefficient for the direct path. Similarly β is the sum of the transmission coefficients for paths such as that shown, by which sound is transmitted into and through the structure and radiated into Q. The total intensity in Q is therefore $I_P(\alpha+\beta)$.

The vibrations in the structure are propagated also to room R, suffering some attenuation, γ, along the additional path length in the structure.

The contribution in R due to this path is therefore $I_P(\beta\gamma)$. To this is added the direct and flanking contributions from Q, amounting to $I_P\alpha(\alpha+\beta)$ and $I_P\beta(\alpha+\beta)$.

Hence the intensities in rooms Q and R are:

$$I_Q = I_P(\alpha+\beta) \tag{1}$$

$$I_R = I_P\{(\alpha+\beta)^2+\beta\gamma\} = I_P\{I_Q^2/I_P^2+\beta\gamma\} \tag{2}$$

The quantity γ was measured directly in the building by exciting a stanchion with a rapid series of impulses from an electric hammer and measuring the vibration spectrum at various distances along it.

At frequencies below 200 c/s the mean attenuation was found to be 7 dB per storey. At higher frequencies the attenuation showed a tendency to rise but the results were variable.

Taking the values of I_Q and I_R at a typical frequency, 88 c/s, from Fig. 4, curves (a) and (b), we have

$$I_Q/I_P = 1{\cdot}58 \times 10^{-4} \quad \text{(Insulation 38 dB)}$$

$$I_R/I_P = 1{\cdot}58 \times 10^{-5} \quad \text{(Insulation 48 dB)}$$

and

$$\gamma = 0{\cdot}2 \quad \text{(Attenuation 7 dB per storey)}$$

Then $I_Q^2/I_P \ll I_R$ and thus approximately, from (2)

$$\beta = I_R/(\gamma I_P) = 7{\cdot}9 \times 10^{-5}$$

$$\alpha = I_Q/I_P - \beta = 7{\cdot}9 \times 10^{-5}$$

α and β are therefore in this case about equal. This is true at all measured frequencies below 125 c/s; above this the experimental accuracy is insufficient but W. Erler[5] finds that for steel and concrete buildings the relative importance of the two types of transmission is substantially independent of frequency.

In room R the ratio between the flanking and direct component is

$$\beta(2\alpha+\beta+\gamma)/\alpha^2$$

As $\beta \triangleq \alpha$ this gives $\dfrac{\text{flanking}}{\text{direct}} \triangleq \gamma/\alpha = \dfrac{0{\cdot}2}{7{\cdot}9 \times 10^{-5}} = 2{\cdot}5 \times 10^4$

This corresponds to an attenuation of 44 dB, indicating that the sound is conveyed to room R almost entirely through the walls and steelwork.

Similar results were obtained from measurements with the tapping machine. Fig. 5 shows the mean sound levels, corrected for reverberation time in the receiving room, due to the machine operating on the floors of the storey above the receiving room (a) and two storeys above (b). Curve (c) represents the sound levels due to transmission through the pillars, estimated according to the method described above. Here, the portion of (c) which lies above (b) is evidently experimental error, but the two curves are so close that the flanking transmission component is probably larger than the direct component.

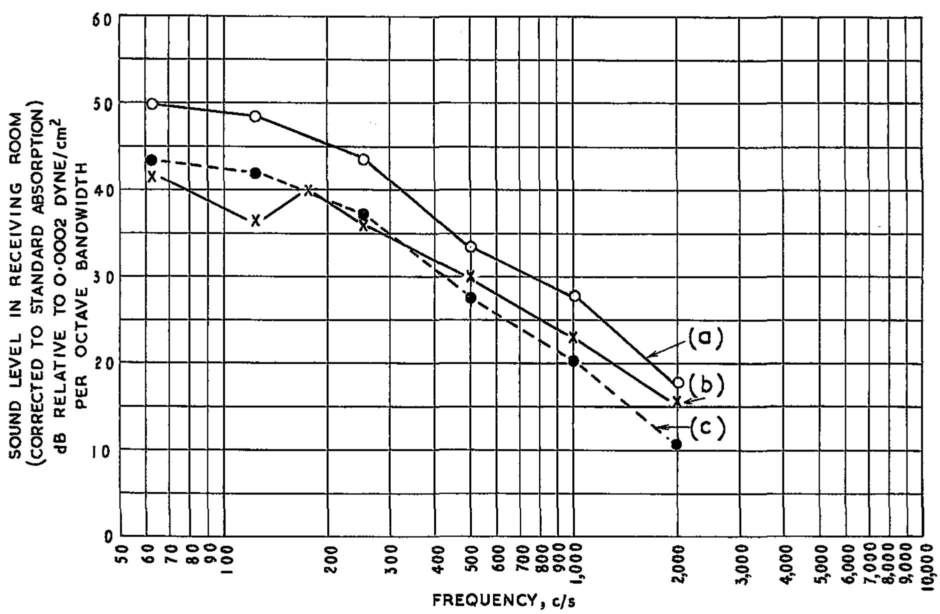

Fig. 5 - Impact sound transmission

(a) between successive floors
(b) between alternate floors
(c) estimated transmission by flanking paths

Comparing the measured figures with the requirements given in Section 2.1, and Fig. 2, it will be seen that the sound insulation afforded by this floor is sufficient for all purposes except at low frequencies. The impact sound transmission is about 8 dB too high generally. As the direct and flanking transmission are of comparable importance, it was decided that the required improvement of, say, 10 dB

could be obtained only by the simultaneous reduction of both. In particular, it was evident that care should be taken to protect the stanchions from accidental impacts, the sound of which would be propagated through the structure to distant parts of the building.

2.3. Design of the Sound Insulation

The design of the studios with respect to sound insulation is conventional in principle. Solid walls are constructed on the existing floors, the studios and cubicles being constructed as separate resiliently mounted structures inside the spaces so formed.

The main dividing walls are built on to the concrete filling over the main beams (see Fig. 3) and pass through the suspended ceiling above, terminating on the beams. The long walls separating the studio suites from the corridors follow the two central lines of stanchions, the walls being arranged to lie flush with the corridor sides of the stanchions. There is a layer of soft fibreboard ½ in. (1·3 cm) thick interposed between the walls and stanchions, to prevent transmission of flexural vibrations between the stanchions and the corridor walls. In some cases the joints thus formed are concealed by light wooden cover strips.

The floors of both studios and cubicles are built on to a light concrete filling added between the wooden sleepers, the battens and floorboards having been removed. On the light concrete is laid a blanket of glass wool covered with Sisalkraft building paper and 2 in. (5·1 cm) of light-weight concrete is poured over it. This slab of concrete is subdivided by joints of soft fibreboard, with the object of reducing its flexural stiffness, and the floor surface is finished with a 1¼ in. (3·2 cm) screed. Fig. 6 shows the construction of the floor and the method of mounting the inner studio and cubicle walls, which are composed of 3 in. (7·6 cm) breeze block and "Camden" partition, respectively. A cork layer isolates the walls from the main floors, thus providing the required additional insulation from flanking and impact sound transmission through the floors.

The internal walls are separated from the main walls by 2 in. (5·1 cm) air spaces and extend to the lower surface of the suspended plaster ceiling. In the case of the studios, they consist of 3 in. (7·6 cm) breeze block surfaced with ¾ in. (1·9 cm) of plaster and carry false ceilings, consisting of plasterboard faced with soft fibreboard, the details of which are described in Section 3.2 below. The inner walls of the cubicles and recording rooms are of "Camden" partition which consists of a layer of ½ in. (1·3 cm) softboard and one of 3/8 in. (0·9 cm) plasterboard on each side of a 2 in. (5·1 cm) wooden framing. The exposed sheet of plasterboard is finished with a skin coat of plaster. There are no false ceilings in the cubicles. Fig. 7 shows sections through the partitions separating a studio from a corridor (a), and a studio from its cubicle (b). To reduce loading on the floors it was decided to replace the breeze inner wall on the cubicle side of each studio by 4½ in. (11·4 cm) brickwork and to omit the brick outer wall. The plastered brickwork and "Camden" partition with a 2 in. (5·1 cm) air space should provide adequate insulation for these positions. Fig. 7(c) shows a section between a studio and an adjacent cubicle serving another studio. Here both outer walls are retained and both inner partitions, giving a four-leaf construction which was considered necessary to attain the insulation represented by Fig. 2, curve (a).

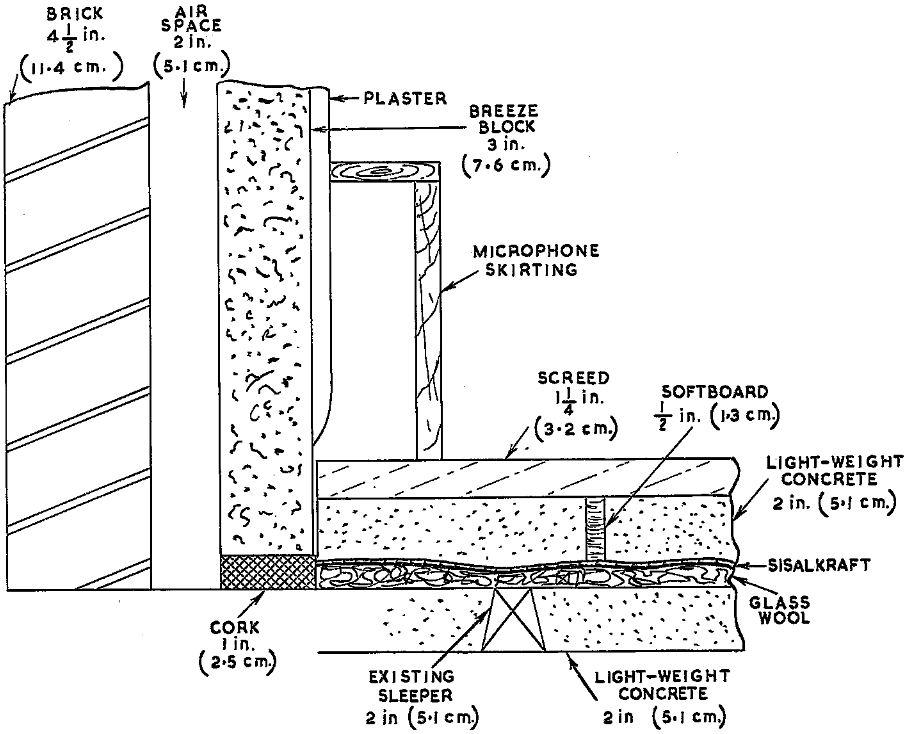

Fig. 6 - Construction of floors and mounting of inner partitions

2.4. Experimental Results

In this section the measured figures of sound insulation between pairs of areas in the studio block will be discussed. The full results are given in the form of tables, and will, in general, receive no detailed comment. The measurements were all made according to the code of British Standard 2750; warbled tone was radiated by a loudspeaker in one of the two rooms between which the sound insulation was to be determined, and the resulting sound levels measured at five positions in each of the two rooms. The intensities for the five positions were then averaged and the two sets compared. Measurements were made at ¼-octave intervals up to 250 c/s and ½-octave intervals thereafter. The tables give the ½-octave intervals throughout, the figures below 250 c/s being averages with the adjacent ¼-octaves. Impact sound transmission was measured by means of the Research Department tapping machine.

2.4.1. Airborne Sound Insulation

Table 1 gives the results of measurements between eight representative studios and their cubicles. Fig. 8, curve (b), is the mean for these eight studios compared with the required curve, (a), which is transferred from Fig. 2, curve (d). The variation between the individual figures is shown by the curves (c) and (d) of Fig. 8, which are the lower and upper limits of individual measurements. Curve (c) falls below (a) consistently because of the performance of one suite only (Continuity 1). There have been few complaints of howl-round or other signs of poor insulation in operational use, however, which confirms that curve (a) represents a fairly safe design criterion.

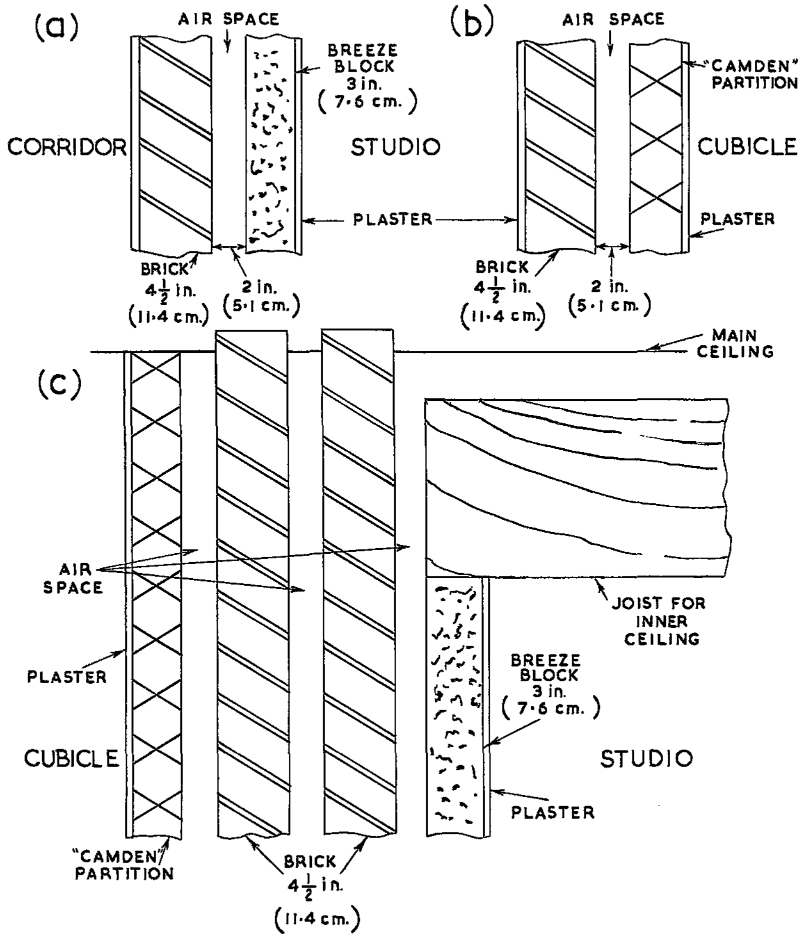

Fig. 7 - Arrangement of partitions and inner ceilings

(a) between studio and corridor
(b) between studio and own cubicle
(c) between studio and another cubicle

Table 2 shows the results of measurements between different studio suites. Columns (1) to (5) are for suites on the same floor while (6) and (7) refer to measurements between successive floors. The bottom row of the table refers to the corresponding minimum value curves. The only case where the measured insulation figures are below the reference curve is that between Continuity Room 2 and the Green Stripes Studio (Col. 2), which are separated only by $4\frac{1}{2}$ in. (11·4 cm) of brick and a "Camden" partition instead of the construction shown in Fig. 7(a), which is usual between suites. The difference between columns (6) and (7) is explained by the presence of the false ceiling in Studio C28.

Table 3 shows the insulation measurements for the control positions on the 6th floor, carried out before completion of acoustic treatment. Columns (1) and (2) refer to adjacent pairs; Column (3), which shows the insulation between Orange Continuity Room and the corridor, is low at most frequencies; this is attributed to

TABLE 1

Results of Sound Insulation Measurements between Studios and their Cubicles

(s = studio c = cubicle r = room)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean
From:	C21s	C22s	C23s	C24s	C25s	C28s	C29s	Cont.1s	
To:	C21c	C22c	C23c	C24c	C25c	C28c	C29c	Cont.1r	
c/s	Sound Reduction Index dB								
50	24	30	24	19	33	33	27	27	28
62	28	32	24	28	35	35	32	29	30
88	32	33	32	36	37	35	37	24	33
125	28	38	40	33	41	35	32	28	35
175	31	42	41	39	40	39	34	29	37
250	40	48	45	43	44	42	36	35	41
350	43	50	50	46	52	48	48	41	47
500	44	51	53	50	55	51	49	49	50
700	51	61	58	56	54	53	53	45	54
1000	48	60	59	57	56	54	58	50	55
1400	55	60	57	57	58	54	57	55	57
2000	57	59	57	54	55	51	54	64	56
2800	56	65	59	51	52	57	57	67	59

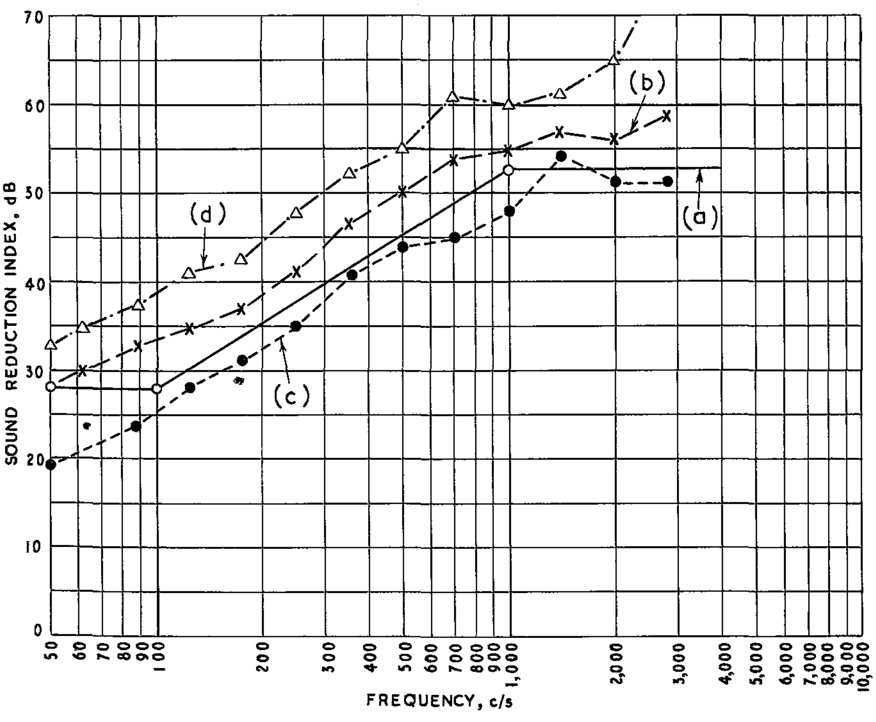

Fig. 8 - Sound insulation between studios and their cubicles

(a) recommendation (from Fig. 2, curve (d))

(b) mean of eight measured curves (from Table I)

(c), (d) lower and upper extremes of individual measurements

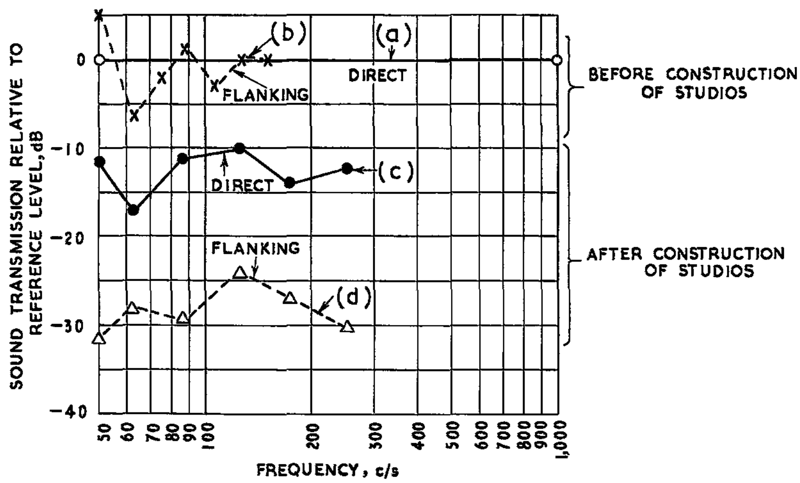

Fig. 9 - Relative contributions of direct and flanking transmission between floors

(a) direct (reference level) before construction of studios
(b) flanking, before construction of studios
(c) direct after construction of studios
(d) flanking, after construction of studios

are expressed in phons derived from summation of octave-band sound pressure levels in the receiving room. All the figures shown are well below the acceptable level of 56 phons; those for areas on the same floor are higher than those for successive floors. There were, however, complaints in service that footsteps on some cubicle floors were picked up by the studio microphones and indicated on the programme meters. In one case, that of Studio C30, where this trouble was particularly bad, it was necessary to lay rubber sponge under the carpet of the cubicle.

TABLE 5

Octave-Band Pressure Levels due to Footsteps Machine

(s = studio c = cubicle)

Footsteps Machine in	Microphone in	Phons	
		Mintz & Tyzzer summation	Stevens summation
C28s	C28c	39	40
C28s	C27s	29	35
Corridor 6th Floor	C27s	46	48
C28c	C26s	17	23
C28s	C26c	25	32
Corridor 5th Floor	C26s	33	39

Further measurements were therefore carried out, using a seismic vibration pick-up instead of a microphone in the receiving room. This equipment is designed to respond to frequencies down to 10 c/s, a frequency which might be significant in

this connection. The tests did not assist in finding an explanation for the low attenuation; it can only be assumed that there are points in the structure where the glass wool layer is locally compressed, forming a virtually solid connection between the floor and the main structure. The method of construction makes this possible if continuous supervision is not exercised, but the assumption could only be checked by destruction of the floor. It would be better in future to avoid floor constructions in which this possibility of local bridging exists. Subsequent experiments on the behaviour of mineral wool mats suggest that they are unlikely to be effective below 100 c/s, even when properly constructed.

2.5. Operational Experience

There have been few adverse comments by the users on the sound insulation or impact sound transmission. Initially, when some studios were in operation but others still in course of construction, it was observed that a good deal of noise from building operations could be heard. Impact sounds can still be heard in some of the 7th floor studios, and it is on this floor that there is excessive impact transmission between some studios and their cubicles. There were complaints of transmission of sound from a piano in Studio C27 to Studio C28. A ventilation duct was found to be the principal transmission path, and appropriate remedial measures were applied.

In recent interviews with 32 regular users of the Centre Block studios, the only other criticism made by more than one person was of interference in Studio C21 from sounds originating in the adjacent corridor and of a tendency for howl-round to develop between the studio microphone and the cubicle loudspeaker. Neither complaint was regarded as serious, but both have been investigated. The insulation between the studio and cubicle is seen from Table 1 to be below average at low frequencies. The lobby between them, being of greater volume and having less absorptive treatment than in the case of the other suites, is more reverberant, and thus more effective as a sound transmission path. Remedial measures have been proposed.

3. ACOUSTICS

3.1. Requirements

All the studios except C27 are speech studios of average size or rather greater. A reverberation time of 0·35 sec was proposed as a basis for design, to be independent of frequency from 62 c/s to 8 kc/s. The dimensions of the studios were largely determined by the floor-to-floor height, and the distance between the main stanchions, modified in both cases by the necessity for double shell constructions. Measures for ensuring good diffusion of sound were also given special study, and this aspect is fully discussed below.

The fulfilment of acoustic requirements by simple functional constructions often used in the past was ruled by the Overseas Services to be inadmissible on aesthetic grounds. For instance, the well-tried perforated covers for porous absorbing materials were excluded except for use on the ceilings, because the regular patterns of holes are said to cause headaches and nausea to some studio users. This is probably connected with the visual effects which have been described by McKay.[6] A search had, therefore, to be made for other coverings which would satisfy all

acoustic requirements together with those of appearance, price, washability and ability to be redecorated or replaced at low cost when required.

A second requirement was that the treatment should yield walls which were substantially flat in appearance, in contrast to the purely functional arrangement of small areas of absorbers upon flat reflecting walls, an arrangement which has usually been adopted to ensure good diffusion.

3.2. Acoustic Design and Materials

3.2.1. The Construction of the Ceilings

With the exception of Studio C21, which was conventional in treatment, each studio was provided with a ceiling designed by Mr. Alexander Brown of the B.B.C. Building Department.

This ceiling combines the required sound insulation and low frequency absorption with rectangular diffusing irregularities, all concealed behind a flat hardboard surface 15 in. (38 cm) from the structural ceiling. Fig. 10 shows the construction. The main support for the ceiling consists of wood joists, 11 in. × 2 in. (28 cm × 5·1 cm) in section. These form the long sides of a number of membrane absorbers 9 in. (23 cm) deep with maximum absorption at 80 c/s, which are disposed irregularly over the ceiling area. The short sides of the absorbers are of thinner timber and the backs of ½ in. (13 mm) soft fibreboard and 3/8 in. (9 mm) plasterboard nailed together. The remaining spaces between the joists are left empty but are closed with sheets of the fibreboard and plasterboard nailed together thus forming coffers 8 in. (20 cm) deep. The backing to the coffers and the membrane absorbers,

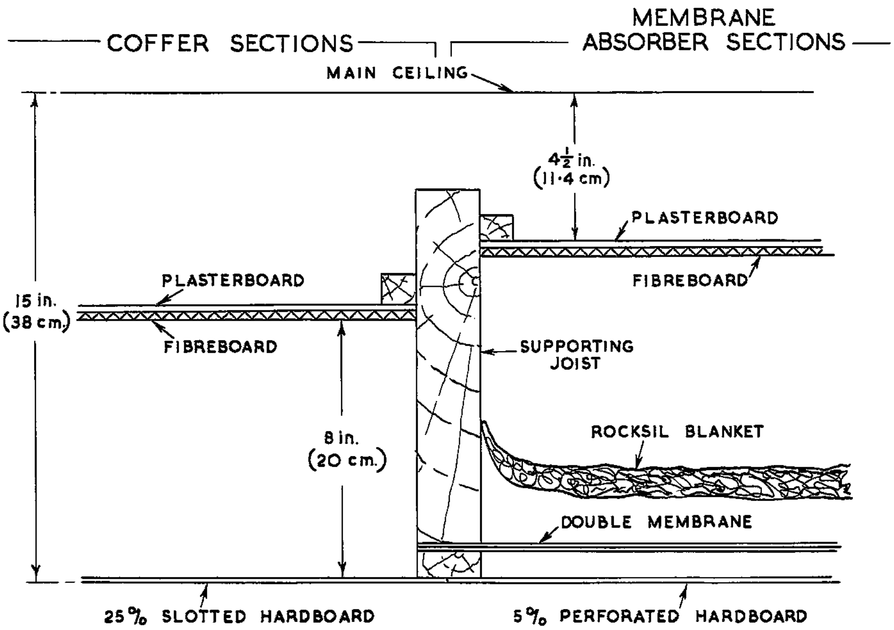

Fig. 10 - Construction of studio ceilings (after Building Department sketch)

in conjunction with the air space of 4 to 5 in. (10 to 13 cm) was expected to increase the sound reduction index of the ceiling by an average of about 10 to 15 dB over the audible frequency range; the information in Fig. 9 shows that this expectation was realised. The front surface of hardboard is perforated with circular holes giving 5% open area in front of the membrane absorbers and slots giving 25% open area in front of the coffers.

3.2.2. Materials for Wall Treatment

The requirements given in Section 3.1 were met by facings consisting of fabrics both draped and stretched, wooden slats and perforated plywoods of dark colour. The latter were permitted since the perforations were not so easily visible against the dark background. Draped curtains were used normally to cover large areas of wall which were partly treated with shallow layers of porous material and partly with deeper absorbers, thus giving a flat appearance. Stretched materials are often deprecated because they require to be washed and, when this is done, shrinkage takes place so that they cannot be re-fitted. Building Department therefore designed detachable frames to carry the facing material together with a surplus length to allow for shrinkage.

Wooden slats of various widths with spaces between are used in many studios to cover low- and middle-frequency absorbers. If the spaces are large enough to be transparent at all audible frequencies, however, it is possible to see the materials behind. In the case of Studio C22, therefore, where wall treatment of particularly elegant and pleasing appearance was required, slatting of special construction, intended to be transparent to sound but not to light, was designed by Building Department and tested by Research Department.

3.2.3. Decorative Grille for Studio C22

Fig. 11 shows a section through the grille. It consists of alternate parallel strips of two different sections. The sample tested was of timber, of dimensions 3 ft × 2 ft (91 cm × 61 cm) although aluminium extrusions were subsequently used for one wall of the studio. It will be seen that there is a fairly wide channel for the passage of sound, but no rectilinear optical paths of less than 45° incidence. It would be expected that the transmission loss through the grille would be significant

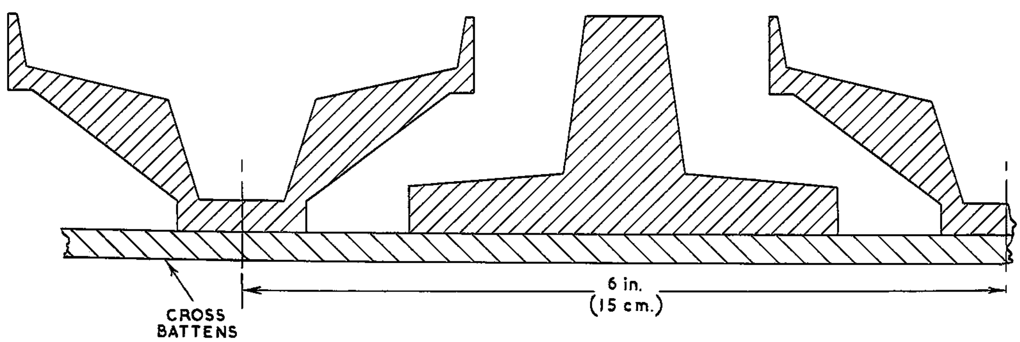

Fig. 11 - Section through decorative grille for Studio C22

for sound of wavelength comparable with or smaller than the width of the channel, but small at lower frequencies, say below 500 c/s.

Before the sample was tested, preliminary measurements were made on typical perforated hardboards, with open areas from 0·5% to 25%. This was necessary to enable the best of several possible methods to be chosen.

The sample was fixed over the front of a box in a small dead room, and warble tone was radiated by a loudspeaker at the other end of the room. The box was lined with a deep layer of rockwool to minimise standing-wave effects, and the level of sound at a microphone a few centimetres behind the sample was compared with that in front, due allowance being made for the divergence of the sound beam. Pulses of tone were also tried, with the object of eliminating the effects of reverberation, but, with the dimensions involved, the maximum length of pulse permissible to avoid interference by reflections from the sample was about 1 msec. This restricted pulse measurement to frequencies above about 1 kc/s.

In another method the closed box was replaced by a wire netting structure supporting 12 in. (30 cm) thickness of porous material, thus reducing reverberation even at very low frequencies.

The first method was the only one which gave a decrease in transmission loss with increase in perforation percentage for the six types of hardboard tested, and it was, therefore, adopted for the measurements on the sample grille.

Fig. 12 shows the mean curve of transmission loss against frequency for sound passing through the grille. It was evident that the grille would cause a substantial reduction at all frequencies above 1 kc/s in the effective absorption coefficient of the materials placed behind it. However, since it was to be used largely for covering low-frequency membrane absorbers, the grille was retained in the design and some additional high-frequency absorption provided elsewhere.

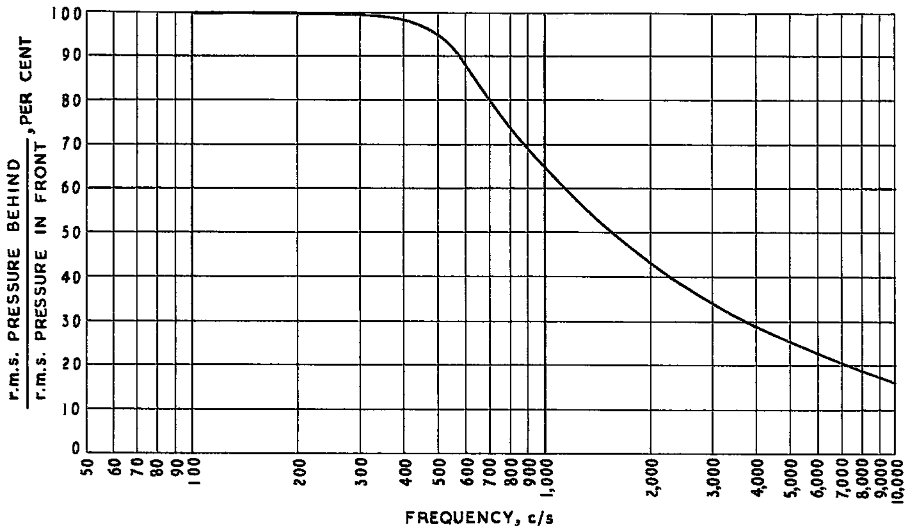

Fig. 12 - Percentage transparency of decorative grille

3.2.4. Absorption by the Structure

In assessing the total additional absorption for the studio and cubicles, allowance was made in the normal way for absorption by vibration of the room surfaces. The influence of the floors was neglected since they consisted of a considerable thickness of light-weight concrete. High absorption was expected from the breeze block and "Camden" partitions, the amounts being calculated from the results of analysis of existing studios. However, the behaviour of these forms of lining appears to vary considerably between different studios, and subsequent measurements show that too much allowance was probably made in the case of the breeze block. (See Section 3.3.2 below.)

3.2.5. Diffusion: The Design of Studios C25 and C26

The design and construction of Studios C25 and C26 offered a rare opportunity of making a full-scale test on the subjective effects of diffusion in small studios. The subjective differences between normally treated studios with good and indifferent diffusion are difficult to define and may be masked by differences in dimensions or reverberation characteristics. For this reason the desirability of building and comparing two experimental studios identical in all respects other than diffusion has long been recognized. Studios C25 and C26 were chosen for this purpose, having identical planned dimensions and lying adjacent to one another. The designs were carefully carried out to ensure similar reverberation characteristics, but, in the case of Studio C26, advantage was taken of the stanchion enclosures to provide irregularities, and additional perturbations were introduced by adding projecting rectangular forms made from plasterboard. In each case, the absorbing materials were distributed in a similar manner over the room surfaces.

Diffusion was provided in all other studios mainly by the irregular distribution of absorbers and by the ceiling arrangement already described. At the time it was feared that the requirements of flat room surfaces might limit the degree of diffusion which would be obtainable, but work which was in progress at the time, now published as a Research Department report,[7] suggests that the arrangements made were probably adequate.

3.3. Results of Acoustic Measurements

3.3.1. Measurements in C21 Suite

The first suite to be finished was C21, consisting of a studio, a recording room and a mixer room. The reverberation time was found to be rather too high between 62 c/s and 175 c/s, even for the fairly large volume of 2730 ft^3 (74 m^3), reaching a maximum of 0·46 sec.

The pulsed glide display showed only one recognisable colouration, at 90 c/s, and listening tests, after selection of the best microphone position, favoured a microphone circuit without bass cut. The results of the acoustic tests on the studio were used in a final examination of the other studio designs.

3.3.2. Preliminary Measurements on the 5th, 6th and 7th Floors

Access to the remaining partly-finished studios was obtained in April 1957. Acoustic measurements were made with the principal object of finding out whether the

estimates of absorption by the structures were correct, or whether the area of added bass absorbers required adjustment. The studios were tested with temporary carpet laid to represent the final finished condition as closely as possible; there were no curtains fitted, and an estimated absorption had to be allowed for them. The cubicles were tested without carpets. The results of these intermediate tests will not be given individually. They showed that the cubicles had approximately the expected total absorption at low frequencies, while the majority of studios had insufficient absorption below 350 c/s. This was most probably due to too high a coefficient having been allowed for the breeze block structure of the studios, that for the "Camden" walling of the cubicles being approximately correct. New mean values for the effective coefficient for breeze block, incorporating the present results in addition to previous figures, are shown in Table 6.

TABLE 6

Structural Absorption Coefficient of Breeze Block Walls

c/s	Coefficient
62	0·09
125	0·13
250	0·16
500	0·03
1 to 8 kc/s	Negligible

Additional low-frequency absorbers, consisting of shallow roofing-felt membrane units over most of the unoccupied ceiling areas, were added to all studios to increase the total absorption towards the design figures.

3.3.3. Acoustic Tests in the Completed Studios

Acoustic tests were carried out in all studios and cubicles during August 1957, and further tests have been made from time to time since that date. The reverberation-time/frequency characteristics of the studios are shown in Table 7 and those of the cubicles in Table 8. Studio C22 is treated separately in a later section. The cubicle of Studio C23 is omitted from Table 8 as measurements were not carried out in its final operational condition; in intermediate tests it was closely similar to the cubicle of Studio C24.

TABLE 7

Reverberation Characteristics of Studios omitting Studio C22

c/s	C21	C23	C24	C25	C26	C27	C28	C29	C30	G.S.	Cont.1	Cont.2	Mean
	Reverberation Time (sec)												
62	0·43	0·51	0·44	0·60	0·48	0·54	0·56	0·40	0·39	0·42	0·36	0·39	0·46
125	0·46	0·36	0·47	0·50	0·46	0·50	0·51	0·45	0·39	0·44	0·40	0·48	0·45
250	0·36	0·36	0·44	0·35	0·42	0·49	0·45	0·38	0·38	0·42	0·42	0·36	0·40
500	0·26	0·27	0·37	0·30	0·37	0·35	0·30	0·31	0·27	0·33	0·31	0·27	0·31
1000	0·20	0·22	0·23	0·25	0·27	0·33	0·24	0·23	0·21	0·28	0·22	0·22	0·24
2000	0·24	0·24	0·30	0·26	0·30	0·38	0·34	0·24	0·26	0·28	0·24	0·21	0·27
4000	0·24	0·27	0·32	0·30	0·30	0·41	0·34	0·28	0·25	0·30	0·28	0·22	0·29
8000	0·24	0·26	0·29	0·29	0·30	0·35	0·30	0·28	0·22	0·33	0·27	0·22	0·28

TABLE 8

Reverberation Characteristics of Cubicles Tested in Final Condition omitting Cubicle C23

c/s	C21	C22	C24	C25	C26	C27	C29	C30	Mean
	Reverberation Time (sec)								
62	0·52	0·42	0·39	0·44	0·43	0·36	0·34	0·38	0·41
125	0·42	0·35	0·36	0·36	0·38	0·35	0·35	0·36	0·37
250	0·46	0·36	0·40	0·43	0·40	0·36	0·31	0·32	0·38
500	0·44	0·32	0·30	0·34	0·36	0·31	0·30	0·31	0·33
1000	0·36	0·26	0·20	0·23	0·23	0·23	0·21	0·25	0·25
2000	0·36	0·29	0·24	0·24	0·25	0·25	0·26	0·27	0·27
4000	0·41	0·30	0·30	0·30	0·31	0·28	0·28	0·30	0·31
8000	0·34	0·31	0·32	0·31	0·32	0·30	0·28	0·32	0·31

The mean characteristic of all studios, with the exception of Studio C22, is shown in Fig. 13, curve (a), and that of the cubicles in Fig. 13, curve (b). Studio C22 is treated separately below, since the design was different from that of the other studios and since major modifications were made after it went into service. The mean reverberation time for the studios over the whole frequency range is 0·34 sec, but the reverberation time is too long below 400 c/s, and shorter than the design reverberation time above this frequency, with a minimum at or just above 1 kc/s. A deficiency in absorption below 400 c/s still remained after the modifications, because there was insufficient area available for the whole of the required additional low-frequency absorption.

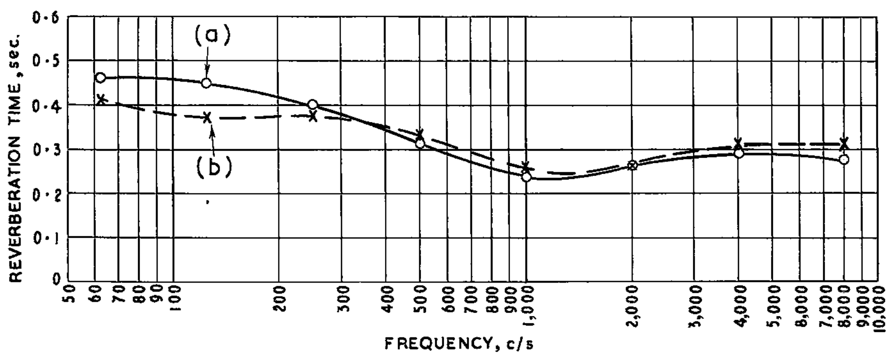

Fig. 13 - Mean reverberation characteristics
(a) all studios, excluding C22, in final condition
(b) all cubicles, tested in final condition

The mean curve for the cubicles is approximately according to design below 500 c/s but above this frequency it is lower than the design curve, reaching a minimum at 1000 c/s. The excess of absorption at this frequency is mainly due to the shape of the absorption characteristic of the standard studio carpet. It has been a disturbing feature of many talks studios designed in the past few years, particularly since the introduction of Wilton and woolcord carpet, which both show peak absorption

in this region. Unfortunately, all satisfactory high-frequency absorbers also absorb well at 1 kc/s, and it is, therefore, difficult to avoid the effect of the peak by the addition of absorption higher in frequency.

A range of absorbers has, therefore, been developed having maxima of absorption coefficient approaching unity at about 300 c/s and 3 kc/s and a broad minimum of about 0·6, at 1000 c/s. It is proposed to introduce these absorbers experimentally into future designs with the object of ensuring more level reverberation characteristics. The absorption characteristic of one such construction is shown in Fig. 14.

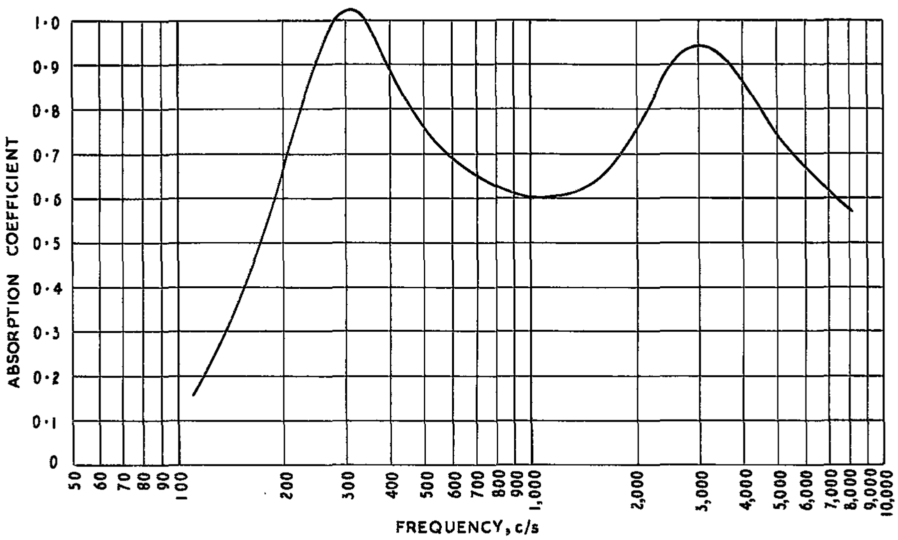

Fig. 14 - Absorption characteristic of experimental absorber for use in talks studios

Quite severe flutters were noticed in Studios C24 and C28, and flutters or rings of less importance in C26, C27 and C30. In every case the flutters originated between comparatively small areas of untreated walls and, in the more severe cases, the areas were flanked by transverse walls having low average absorption coefficient. It would, therefore, appear to be necessary to take particular care to avoid even small opposite reflecting areas in such situations, presumably because the presence of the flanking wall has the effect of doubling the effective areas of the surfaces in question.

Experiments showed that the flutters could be damped by patches of absorber less than 1 m^2 in area, and it was recommended that such a remedy should be applied. 1 in. (2·5 cm) deep frames containing rockwool covered with a thin washable membrane were therefore installed and had the desired effect.

3.3.4. Acoustic Tests in Studio C22

Owing to its unorthodox treatment, the test results on Studio C22 differed greatly from those from the other studios. The main features of the reverberation characteristic were a deep dip at 500 c/s and excessive reverberation at both ends of

the spectrum, where it rose to approximately 0·6 sec. There were severe rings at 500 c/s and 1000 c/s. It could not be ascertained whether the rings were associated with the regular arrangement of the slats, which had a pitch of 6 in. (15 cm) or with the non-uniform distribution of mean absorption coefficient between the three pairs of surfaces.

The deficiency of upper-frequency absorption, which had been expected from the laboratory results on the slat coverings, had not been compensated for, and the wall furthest from the cubicle was entirely covered by slats. There was little treatment on the opposite wall. It therefore appeared probable that the slats were directly or indirectly responsible for both the rings and the excessive high-frequency reverberation.

Measurements were made in the studio with all the slats removed. Fig. 15, curve (a), shows the reverberation characteristic with the slats present, while in Fig. 15, curve (b), all slats have been removed. The removal of the slats caused a useful reduction in high-frequency reverberation, but there were still peaks at 175 c/s, 1000 c/s and 5,600 c/s. The slats were replaced and 33 ft² (3·1 m²) of curtain added over an area of slat-covered absorber in the middle of the short wall further from the door. This caused a considerable change in the reverberation characteristic (Fig. 15, curve (c)), but the rings and excessive reverberation at some frequencies remained.

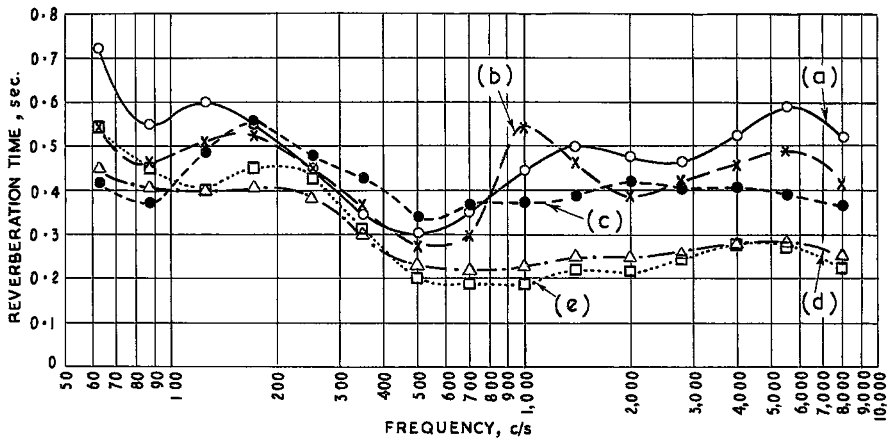

Fig. 15 - Reverberation measurements in Studio C22

(a) original condition
(b) all slats removed
(c) 33 ft² (3·1 m²) curtain
(d) 142 ft² (13·2 m²) curtain over slats
(e) present state after modification

It was therefore decided that removal or covering of some of the slats was necessary and this was arranged temporarily, using 142 ft² (13·2 m²) of curtain, two-thirds of which was draped over the central part of the long slatted wall and the remaining third in two equal areas on the short wall adjacent to the door. Fig. 15, curve (d), shows the result, the characteristic being the same within the accuracy of measurement whether the slats were removed from behind the curtained areas or not.

The presence of these curtains eliminated the rings entirely and the substantial reduction of the 1000 c/s peak of reverberation is due to the suppression of flutters between the two long walls. The peak of reverberation just above the cut-off frequency of the slats was due to the fact that the absorption coefficient of the slat-covered material was low at about this frequency and the two facing walls were almost completely reflecting.

Fig. 15, curve (e), shows the final characteristic resulting from the replacement of the temporary curtains by a smaller area of permanently fitted curtaining on the two slatted walls.

3.3.5. Studios C25 and C26

The design of these two studios was discussed in Section 3.2.5 above. Fig. 16 shows the reverberation characteristics of the two studios. The non-diffused Studio C25 has a higher reverberation time in the extreme bass, but lower elsewhere. It was considered that the differences between the characteristics were not great enough to mask the differences due to diffusion, and some listening tests were made using both live speech and recordings. The results were inconclusive. A full subjective investigation will, therefore, be made as soon as possible, after equalising the reverberation characteristics as closely as possible by means of portable absorbing units. The results will be given in a later report.

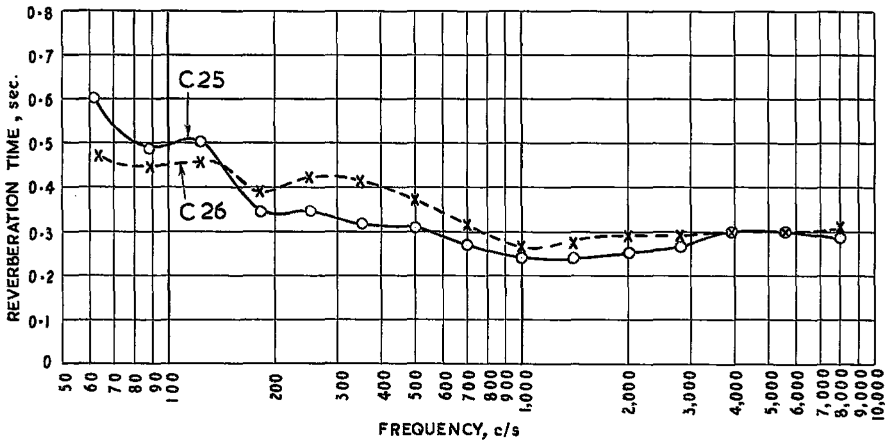

Fig. 16 - Reverberation characteristics of Studios C25 and C26

3.4. Summary of Users' Opinions

Some indication of the users' voluntarily expressed opinions was obtained during the interviews previously mentioned in Section 2.5. Each subject was asked to comment on any studios, whether in Bush House or elsewhere, on which he was willing to express an opinion. Most preferred to comment on studios having well-defined faults rather than on good or indifferent studios. Comments from more than one subject were obtained for eight Centre Block studios. The liveness was considered correct in all cases except those of Studios C21 and C22 which were considered insufficiently reverberant. The reverberation characteristics are, indeed, the lowest two of all the Centre Block studios.

Low-frequency colourations were mentioned in connection with the same two studios, while sibilance and flutters were considered the main defect of C25. There were no other adverse criticisms of the small studios. C27, however, which is a large studio, being used for general purposes, has been found insufficiently reverberant for many types of programme.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The studio and cubicle sound-insulating constructions described in this report are satisfactory having regard to the fact that all the studios except one are for speech alone. However, they represent the minimum which could give satisfactory results within an existing steel-framed building.

2. Impact sound insulation is generally satisfactory but there are instances of unexpectedly high transmission of the low-frequency components of footfalls from cubicles to their associated studios. This has not been satisfactorily explained and it is doubtful whether it can be fully investigated now that the structure is obscured by the completed surfaces. A method of floor construction less liable to accidental local bridging and giving a lower fundamental resonance frequency is recommended for the future.

3. The reverberation times of the studios are generally too long below 400 c/s and rather too short above this frequency. The cubicles are nearer to their designed characteristics. The excess of reverberation at low frequencies is probably due to the assumption of too great a structural absorption for the breeze-block inner leaves of the studios. A dip in the characteristics at 1000 c/s common to studios and cubicles here and elsewhere is associated with woolcord carpeting and, in view of the difficulty of compensating for the peak in the absorption coefficient of this material, a range of special absorbers has been developed.

4. Diffusion seems to be adequate in most studios, though flutter echoes could initially be heard from certain positions in a few of the studios. In most cases, the flutters were caused by comparatively small areas of reflecting wall facing each other across the studio and they have been cured. Where opposite reflecting walls are the cause, the effects are worst if the two reflecting surfaces meet a common wall which is mainly reflecting. In all cases it was found that the introduction of quite small areas of absorbing material in the reflecting surfaces was an effective cure.

5. Inconclusive results were obtained from a subjective comparison of Studios C25 and C26, although these were designed to be identical in dimensions and reverberation characteristic but different in diffusion. A more thorough investigation has been started and will be reported elsewhere.

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